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Short Communication

Invasive non-native fish species in the Yangtze River: A looming ecological crisis and mitigation strategies

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Abstract

The Yangtze River is China's essential ecological resource and a historically revered "mother river" intimately tied to her ancient civilization. In recent years, the river has faced escalating threats from non-native fish species introduced by anthropogenic activities, including prayer animal release, aquaculture escapes, and deliberate pet abandonment. With a low current population density, these exotic species pose limited immediate ecological risks. However, the ecological damage will be catastrophic in the long run once they successfully establish large and stable populations and become invasive. To effectively address this challenge, comprehensive measures can be applied, including strengthening risk assessment, controlling reproduction and transmission, suppressing new introductions, improving regulations and policies, enhancing public education and prevention awareness, and strengthening multi-party cooperation. This study contributes new insights into the dynamics of invasive species in the Yangtze River and the broader implications for freshwater ecosystem management by reviewing current knowledge.

Key words: Conservation, non-native fish species, Yangtze River

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Introduction

The non-native species may cause significant ecological and economic losses upon successful invasion. The intruders achieving a high invasion success can trigger snowballing ecological disasters. They may reduce the number of indigenous species and decrease their genetic diversity through competition, predation, or hybridization (Britton 2023; Galland et al. 2024). When alien species interbreed with native relatives, it may lead to the genetic contamination of indigenous species or even genetic extinction (Meilink et al. 2015; Zhan et al. 2017). In economic terms, the cost of biological invasions worldwide was estimated to be US$162.7 billion in 2017 alone, which was strongly underestimated and has not shown any sign of slowing down (Diagne et al. 2021).

From the perspective of community structure, alien species invasion may lead to the homogenization of community structure (Wong et al. 2020).

By virtue of their strong competitiveness and adaptability, they may quickly ascend to a dominant position, excluding indigenous species, thus significantly reducing the community's species diversity. At the ecosystem level, the destructive power of invasive alien species cannot be ignored. They may cause profound damage to the ecosystem by disrupting its structure and function (Green and Grosholz 2021). In addition, some alien species can carry new diseases that may be transmitted to other aquatic organisms, and the pathogen may cross the species barrier to infect humans (Roy et al. 2023). Based on the principle of instant pathogens, the resident species and humans with no co-evolutionary interactions and, hence, little resistance to the newly introduced diseases, may succumb calamitously.

The Yangtze River is the cradle of Chinese civilization and an important ecological barrier area. Its unique ecosystem is important in maintaining biodiversity and safeguarding the country's ecological integrity. Over the years, the Chinese government has adopted a synergy of measures to protect the river, including research, legislation, regulation, governance, public education and community engagement. Nevertheless, the Yangtze ecosystem still faces many challenges, including the aggravating problem of alien species (Chen 2020). However, investigating the introduction of aquatic fauna has received inadequate attention (Magellan 2019).

In this study, based on literature collections about non-native fishes in the Yangtze River, we pursue several objectives: (1) compile a list of field observed non-native fish species in the Yangtze River Basin and their origins, (2) annotate the drivers of biological invasions in this river, (3) propose measures to deal with the foreign fishes.

Methods

Study area

The Yangtze River, as the longest river in Asia and the third-longest globally, stretches 6,387 km with a basin area of 1.8 million km^2, flowing through 11 provincial- level regions from the Tibetan Plateau (elevation exceeding 5,000 m) to the East China Sea (Zheng et al. 2020) (Fig. 1). Its basin spans 25° of longitude (90°–122°E) and 10° of latitude (24°–35°N), encompassing diverse landscapes: alpine glaciers, deep gorges (e.g., Three Gorges), expansive floodplain lakes (e.g., Dongting and Poyang), and fertile delta wetlands. The ecosystem harbors exceptional biodiversity, supporting more than 378 fish species/subspecies (e.g., critically endangered *Acipenser sinensis* and *Neophocaena asiaeorientalis*), 121 annelids, 318 molluscs and 594 arthropods (Yu et al. 2005; He et al. 2019).

Data collection

In the present study, fish occurrence data for the Yangtze River were compiled from published latest literature (Yang et al. 2024). In the current work, two different kinds of non-native fishes have been considered: (1) translocated fish species that are native to China outside the Yangtze River Basin and (2) exotic fishes introduced into Yangtze River from other regions or countries.

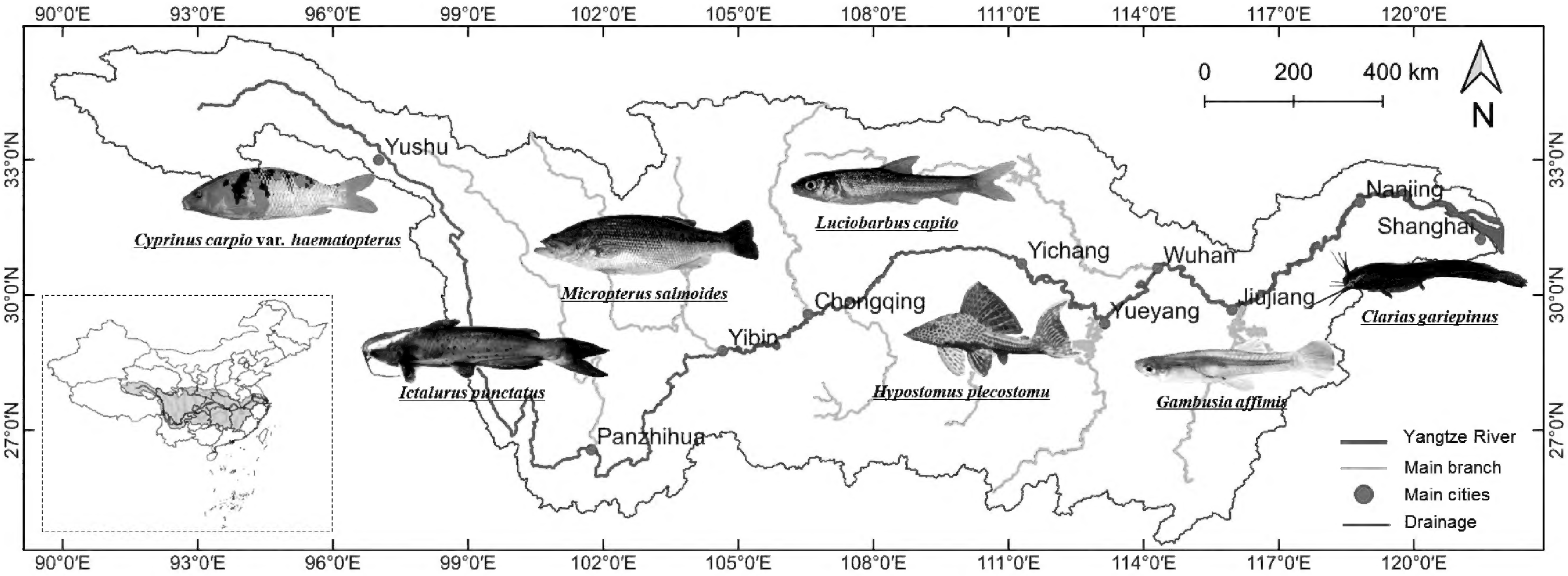

Figure 1. The Yangtze River Basin showing the river course and its major tributaries. Selected examples of invasive fish species are inserted into the map not in relation to their actual distribution.

Results and discussion

The latest survey recorded 33 exotic fish species dwelling in the river (Yang et al. 2024) (Table 1). Except for the hybrid sturgeon, 16 species are native to waters of China outside the Yangtze River. They come from widely distributed geographic areas, including the northeastern, northern, northwestern, southwestern, and southern regions, including the Pearl River Basin. The other half of the exotic species, not native to China, originate from almost cosmopolitan source areas covering Asia, Africa, North America, South America, and Europe.

Reasons for the current fish introductions

Most of these fishes have ornamental or edible value. Their presence in the Yangtze River Basin is not the result of natural ecological evolution or migration but is directly or indirectly attributed to anthropogenic factors. Prayer animal release is one of the main reasons for their intentional introduction to the Yangtze River system (Magellan 2019). In China, releasing captive wildlife to different ecosystems is a cultural phenomenon deeply rooted in the religious spirit of compassion and kindness, occupying a pivotal and ingrained status, especially in Buddhism and Taoism cultures. The operation can range from an individual's small-scale release to massive ceremonial or ritualized release. The practitioners intend to convey respect and care for life, earn propitious blessings, and receive merit or good karma. Even with the best intentions, the practice is tantamount to the advertent introduction of non-native and possibly invasive species to receiving ecosystems (Du et al. 2024). For instance, *Misgurnus anguillicaudatus* and *Paramisgurnus dabryanus*, two non-native fish species often introduced by prayer release, pose a threat to the survival of *Ptychobarbus chungtienensis* in Bita Lake, Yunnan province, China (Jiang et al. 2016).

In addition to releases, escapes from aquaculture facilities constitute another major cause of non-native fish entering natural waters (Ju et al. 2020). Extreme weather conditions, damage to aquaculture facilities, improper management and human negligence can generate opportunities for farmed fish to escape into the natural environment. Some aquaculture farmers may accidentally release captive fish into the wild environment when they fail to properly handle pond cleaning

Table 1. List of the alien fish species in the Yangtze River (the species list is derived from Yang et al. 2024).

Order	Family	Species	Native species in China*
Acipenseriformes	Acipenseridae	*Acipenser schrenckii*	Yes (Heilongjiang Province)
		Hybrid Sturgeon	Artificially cultivated
Cypriniformes	Cyprinidae	*Rhynchocypris lagowskii*	Yes (Heilongjiang Province)
		Tinca tinca	Yes (Xinjiang Province)
		Sinibrama macrops	Yes (Taiwan Province)
		Pseudohemiculter dispar	Yes (Pearl River system)
		Megalobrama terminalis	Yes (Hainan Province)
		Luciobarbus capito	No (Armenia, Azerbaijan, Georgia, Iran, Russian, Turkey)
		Percocypris regani	Yes (Lancang, Nanpan River system)
		Acrossocheilus paradoxus	Yes (Taiwan Province)
		Cirrhinus molitorella	Yes (Hainan, Taiwan Province)
		Cirrhhina mrigala	No (Bangladesh, Nepal, Pakistan, India)
		Labeo rohita	No (Pakistan, India, Bangladesh, Myanmar, Nepal)
		Cyprinus carpio specularis	No (Europe)
		Cyprinus multitaeniata	Yes (Guangxi Province)
		Cyprinus carpio var. *haematopterus*	Artificially cultivated
	Cobitidae	*Barbatula nuda*	Yes (Liaoning, Inner Mongolia, Jilin, Heilongjiang, Hebei, Xinjiang Province)
		Misgurnus mohoity	Yes (Heilongjiang Province)
		Cobitis sibirica	Yes (Heilongjiang Province)
Characiformes	Characidae	*Piaractus brachypomus*	No (Amazon Basin)
Siluriformes	Loricariidae	*Hypostomus plecostomus*	No (Amazon Basin)
	Bagridae	*Leiocassis argentivittatus*	Yes (Pearl River system)
	Clariidae	*Clarias batrachus*	No (Indonesia)
		Clarias gariepinus	No (Nile Basin)
	Ictaluridae	*Ictalurus punctatus*	No (North America)
		Ameiurus nebulosus	No (North America)
	Pimelodidae	*Phractocephalus hemioliopterus*	No (Amazon, Orinoco River Basin)
Cichliformes	Cichlidae	*Oreochromis niloticus*	No (Africa)
		Oreochromis mossambicus	No (Africa)
Cyprinodontiformes	Poeciliidae	*Gambusia affinis*	No (North and Central America)
Perciformes	Centrarchidae	*Micropterus salmoides*	No (North America)
	Serranidae	*Coreoperca loona*	Yes (Hunan, Guangxi, Jiangxi, Guizho, Fujian Province)
	Percidae	*Sander lucioperca*	No (Europe)

Notes: *: The term refers to native to rivers and freshwater bodies outside the Yangtze River range in China; Yes: The species is native to China outside the Yangtze River range; No: The species is not native to China.

or variety switching. Abandonment by fish hobbyists due to waning or shifting personal interests, inability to handle the large grown-up size, or other reasons, can trigger the deliberate release of pet fish into natural waters (Xie et al. 2023).

Invasiveness traits and ongoing risks

Adding non-native species to ecosystems denotes a chronic anthropogenic pathway for biological invasions in many countries. The cumulative effects of the continual insertion year after year can bring far-reaching and ecologically

harmful repercussions to local ecosystems. In the early stages of exotic species entering a new habitat, the novices usually do not immediately present a serious hazard to the adopted ecosystems (Reaser et al. 2020). The limited genetic pool and founder effect of the initially small subpopulation restrict the ecological influence and reproduction of the alien newcomers. The fulfillment of certain conditions will change the fresh recruits from harmless "immigrants" to harmful "invaders" (Museth et al. 2007).

Successful invasive species are usually characterized by wide ecological amplitudes, high stress tolerance, and high reproductive capacity (Prokopuk and Zub 2020; Gracida-Juárez et al. 2022). To some extent, the 16 non-native fish species in the Yangtze River have demonstrated such invasiveness traits. Among them, *Micropterus salmoides*, *Oreochromis mossambicus*, *Clarias batrachus*, and *Gambusia affinis* are even listed included in IUCN's "100 of the World's Worst Invasive Alien Species" (Lowe et al. 2000). In large rivers in Southern China, *Hypostomus* sp. and *C. gariepinus* have established natural populations and are regarded as "successful invaders" (Gu et al. 2018).

In addition to the inherent invasiveness of the introduced species, the invasibility of the receiving site affects the invasion success and biological invasion rate (Su et al. 2023). The higher native diversity is an important factor in resisting invasion by exotic fish (Carey and Wahl 2010). The exotic fishes are more likely to become invasive in water bodies with low biodiversity than those with high biodiversity. A worrying fact is that compared to the historical period, there are 47 fewer indigenous species, 27 fewer endemic species, and 11 more invasive species in the upper and middle reaches of the Yangtze River (Wang et al. 2024). This insidious and decided shift in fish species provenance signifies the degradation of the resident population accompanied by the expansion of new arrivals. It may spell the progressive replacement of the former by the latter. Besides invasion by exotic species, the native fishes of other Chinese waters intruding into the Yangtze River should not be neglected. A convincing example is *Pseudorasbora parva*, native to lowland China, which has successfully invaded the faraway alpine freshwater ecosystems of Western China's Qinghai-Tibetan Plateau (Ding et al. 2019).

In recent years, the Yangtze River Basin ecological environment has experienced positive changes due to government efforts (Qin et al. 2022; Zhang et al. 2024). These changes, such as the marked improvement in water quality and the gradual restoration of aquatic biological resources, signify that the Yangtze River ecosystem is moving toward better ecological health and balance. Despite these curative measures, the Yangtze River Basin continues to be affected by economic development activities, such as the construction of large-scale water conservancy projects and urbanization. The loss and fragmentation of natural habitats may facilitate invasion by exotic biota (Haworth and Bestgen 2024). It should be noted that the "ten-year fishing ban" policy was implemented in the Yangtze River in 2020 (Ministry of Agriculture and Rural Affairs 2019). This rule effectively protected the river's indigenous fish species but brought the collateral effect of protecting the invasive species, providing both groups with more secure living and breeding space.

The invasion of exotic species is a complex ecological process. The invasion of the Yangtze River is still in its early stages. Thus far, the introduced species have not yet formed sufficiently large populations (Yang et al. 2024) and will

not cause much harm for the time being. However, they can increase their numbers and invasion level in time to cause more harm. Some invader species may be naturalized in the new habitats to become dominant or even replace some native species. Their continued range-filling activities will take up more potential distribution range to further expand the damage to river ecology. Without mitigation, the looming invasion impacts have a high chance of degenerating to an unacceptable level. Alien species invasion can threaten China's biodiversity and ecological security and directly affect public health. Therefore, this crucial issue has been elevated to the level of national security strategy.

Mitigation measures and strategies for control

Timely and effective intervention at the early stages of a biological invasion is essential to prevent further spread, mitigate management difficulties and costs, and safeguard ecosystem integrity (Robertson et al. 2017). Some response measures can be proposed. Firstly, it is crucial to establish and strengthen risk assessment and early warning mechanisms. The proposed recommendations include improving the quantitative evaluation index system to ensure scientific accuracy (Luo et al. 2022), conducting an invasion risk assessment to identify current and potential high-risk areas and species (Liang et al. 2014; Lieurance et al. 2023), and real-time monitoring and warning (Katsanevakis et al. 2023).

Secondly, the core task of controlling the reproduction and spread of exotic fish should be applied rigorously. This involves artificial capture and removal measures to directly shrink the alien fish population (Fujimoto et al. 2021), and enhancing aquaculture management and regulatory practices to prevent the escape of artificially bred alien fish into natural waters (Gu et al. 2022).

Thirdly, prayer animal release can be modified or replaced by compassionate alternatives in light of modern scientific knowledge and the adulterated commercialized capture-release regime. The message of the undesirable consequences to the captured fauna in the source ecosystems and the impacted fauna in the receiving ecosystems can be ardently conveyed to persuade a change in the religious attitude and behavior of well-defined target groups. The immense suffering and high mortality during animal capture in the wild, trading and after release should be emphatically driven home (Shiu and Stokes 2008). This measure should be accompanied by strict control of the illicit international trade in the affected wildlife.

Furthermore, enhancing the legislation and policy system is a crucial safeguard. The introduction, spread, and effects of invasive species may be suppressed by enacting and enforcing enlightened nature conservation laws (Li et al. 2020). Meanwhile, policy guidance and incentives can spur the public to participate actively in tackling biological invasions (Pasko and Goldberg 2014). In addition, strengthening publicity and education could not be ignored. It is helpful to enhance citizen science activities to raise public awareness of the causes, consequences and countermeasures of the invasive alien species (Zhao 2024). Through the media, networks, and other channels, knowledge and prevention and control methods can be widely disseminated to enhance the citizens' awareness of and responsibility for ecological protection. Finally, there is a need to establish a collaborative network of stakeholders, including citizens affected by invasive species, government departments, scientific research institutions,

non- governmental organizations, businesses, and industry (Shackleton et al. 2019; Zachary 2023). The core of success lies in effective actions through scientific guidance, voluntary participation of concerned parties with convergence of interests and goals, and realization of sustainable and deep cooperation.

Conclusions

The Yangtze River ecosystem has long been a source of biodiversity and economic vitality. The alarming introduction of non-indigenous fish species to the river presents critical challenges that demand urgent and sustained attention. The deleterious impacts of biological invasions in rivers have not received adequate attention compared with terrestrial ecosystems. Addressing this problem requires a holistic and proactive approach, calling for collaborative endeavors across different sectors of society. Only through these combined efforts can we hope to safeguard the Yangtze River's unique biodiversity and ecosystem services, ensuring that it will continue to nourish the environment and the millions of people who depend on it. The time to act is now, for preserving this iconic and pivotal waterway is not just an ecological imperative but a responsibility we must honor for future generations.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Dawei Liu and Xiaoming Xue conceived and designed the research; C. Y. Jim reviewed and edited; Senlin Hou and Dawei Liu performed the research; Dawei Liu and Chunping Xie wrote the original draft. All authors had read and agreed to the published version of the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text.

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